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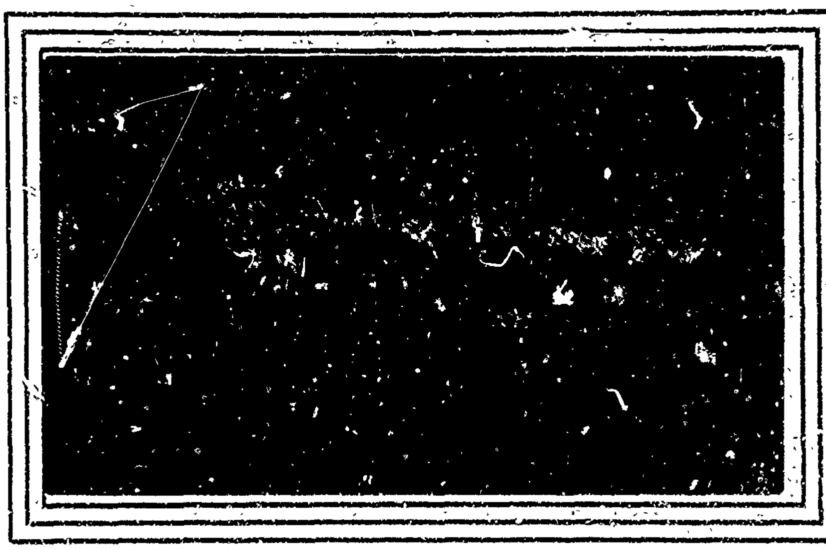

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EXPERIMENTAL HIGH INTENSITY
FLARE SYSTEMS DATA
REDUCTION AND ANALYSIS

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ABSTRACT

The data from the experimental high intensity flare systems tested at the MAPI test site at NAD Crane was reduced to foot-candle, candlepower, and average candlepower measurements and was analyzed for significance. There was no large significant difference in candlepower shown between systems of flares. The horizontal multiple flare systems rated slightly higher in average candlepower than the vertical multiple flare systems. The candlepower was approximately directly proportional to the cross sectional area of the flare. There was good correlation between tunnel data and MAPI data for the Mk 24 Flares. The burning rates for all systems were about the same.

TABLE OF CONTENTS

EXPERIMENTAL HIGH INTENSITY FLARE SYSTEMS DATA REDUCTION AND ANALYSIS

INTRODUCTION

The following is a report on the reduction of the data taken at the Multi-Aspect Assessment of Pyrotechnic Illumination (MAPI) test site at NAD Crane and an analysis of test data of experimental high intensity flares. The steps taken in reading and simplifying the data and arriving at a candle-power measurement for a flare are discussed. A flow chart for the data reduction is shown on page 2 . The data for the high intensity flare systems was analyzed for significant difference between types. Mk 24 data is given as a standard for comparison purposes. Other flare characteristics including burning rates, efficiencies, etc., were also investigated.

DATA REDUCTION FLOW CHART

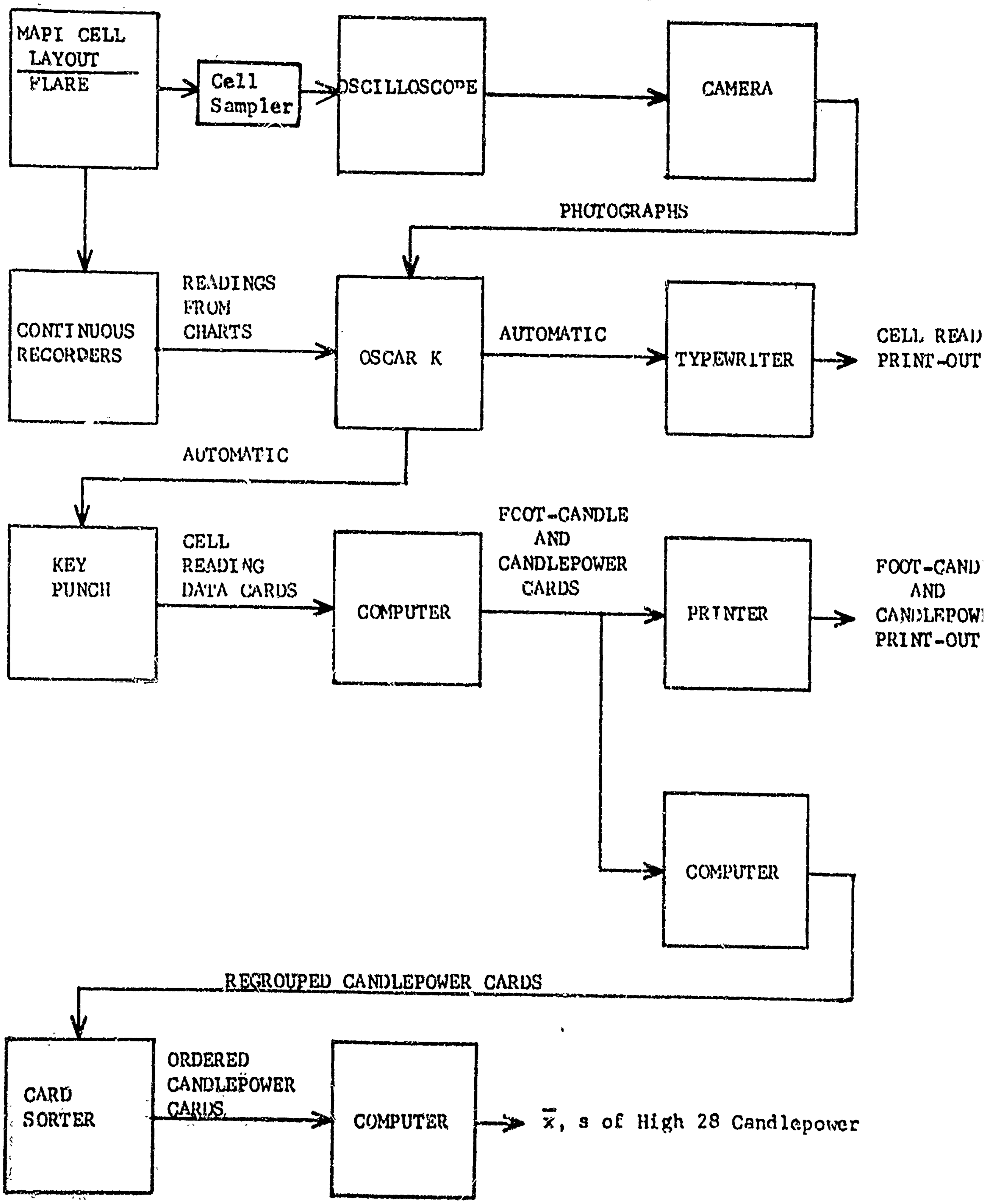
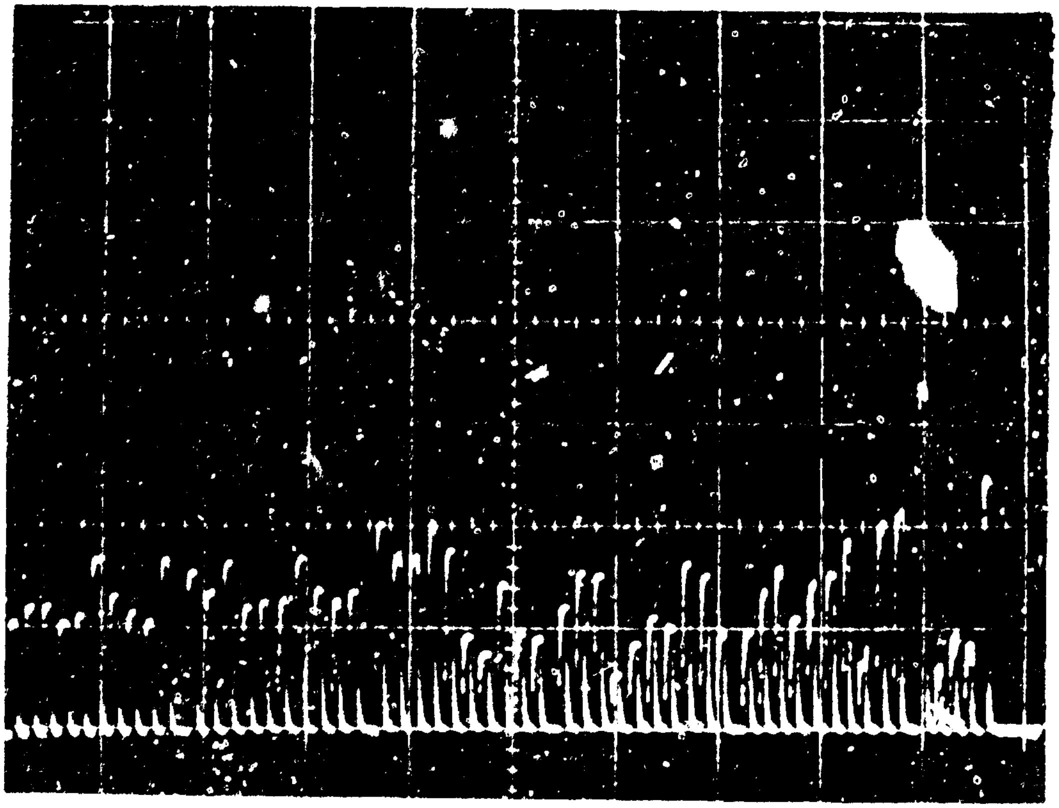


FIGURE 1

DATA REDUCTION

1. Data Received. The data is collected in the form of photographs of an oscilloscope trace and graphs from continuous recordings. There are up to eight samples in time (8 photographs) for each flare tested. On the photographs there are readings from 57 photoelectric cells which yield 57 spikes. The heights of the spikes correspond to voltages produced with full scale (5 major divisions of the oscilloscope grid) being 10 millivolts. Figure 2 is a sample of this type of photograph. Two photoelectric cells are connected to recorders which give continuous traces of voltage output. Time markings are made on the continuous recordings to show the time the samples on the photographs were taken. Figure 3 shows the grid pattern of the MAPI photoelectric cell layout which includes 53 cells on the ground (including the two cells which are connected to continuous recorders) and 6 cells on the towers. The ground cells labled R_1 and R_2 are connected to the two continuous recorders.

2. Reading of Data. Reading the data from the photographs requires the measurement of the heights of the 57 spikes. This is done by using an Oscar K reader which automatically operates a key punch and a typewriter. A picture of the Oscar K with typewriter and key punch attached is shown in Figure 4. The Oscar K is first calibrated so that full scale equals 5 major divisions of the oscilloscope grid on the photographs. The Oscar K gives readings from 000 to 999 which corresponds to 0 to 9.99 millivolts. The photograph is placed on the Oscar K and aligned so that the zero position of the Oscar K coincides with the oscilloscope base line on the photograph. Taking a reading then amounts to adjusting two knobs so that two lines intersect on the bright spot



DATA PHOTOGRAPH

PHOTOCELL LAYOUT AT MAPI TEST SITE

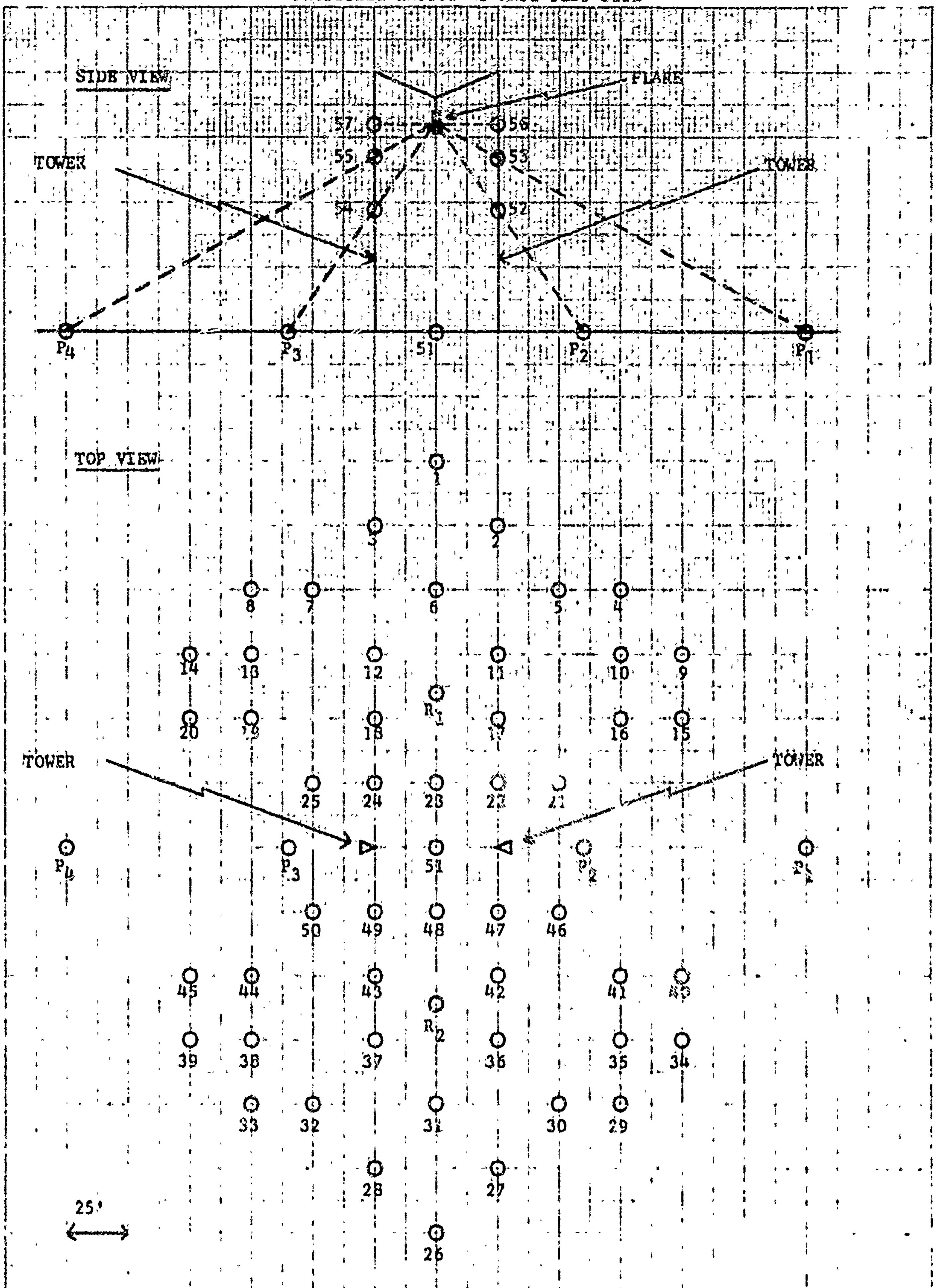
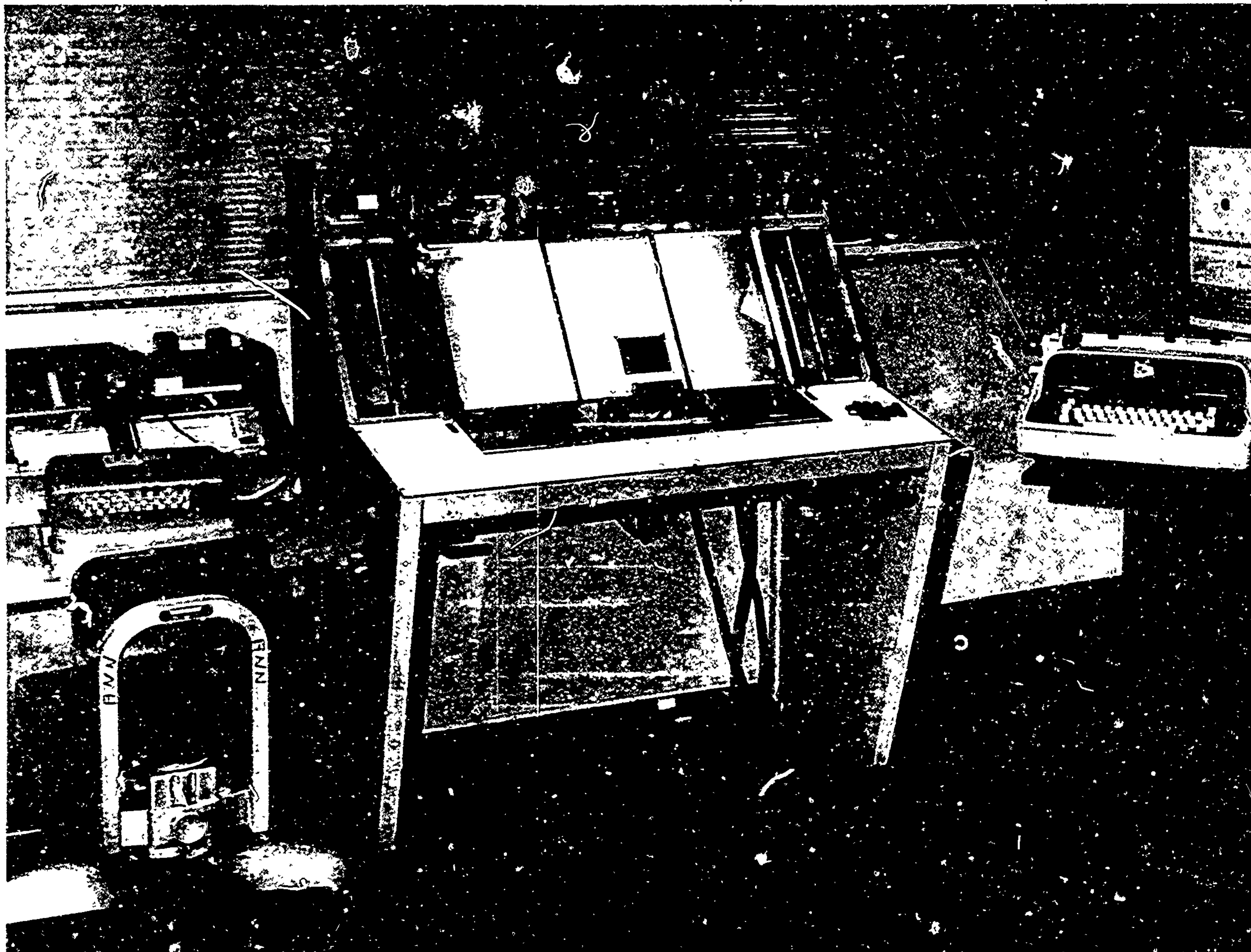


FIGURE 3



[illegible] WITH TYPEWRITER AND KEY PUNCH ATTACHED

FIGURE 4

at the top of the spike being read and pressing a button. The data from the Oscar K, which includes sample number, cell number, and cell reading, is punched on cards for computer processing and also typed at the same time to give a printed copy of cell readings for checking and for future reference. The sample number is set on a dial at the beginning of each photograph and the cell number records automatically. After the 57 readings are taken, the readings at this sample in time from the two continuous recordings are keyed into the Oscar K by hand. The average time required by using the Oscar K is 4 to 5 minutes per photograph which is much less than would be needed to read the photographs by hand and punch the data on cards by hand.

3. Data Processing.

a. The data cards from the Oscar K along with cell calibrations and the square of the distances from each cell to the flare are fed into a computer programmed to compute foot-candles and candlepower for each cell. Corrections are made to the values of cells 52, 53, 54, and 55 which are on the towers to project them onto the ground to points P_1, P_2, P_3, and P_4 as can be seen in Figure 3. The foot-candle and candlepower information is punched on cards from which a print-out is made for each, foot-candles and candlepower, showing all samples in time (in adjacent columns) for all cells for each test. The data on these cards also include test number, sample number, and cell number. These cards will be kept on storage for future use or reference. For the purpose of computing an average candlepower, the candlepower data from this set of cards is regrouped by a computer and punched on another set of cards which can be sorted automatically.

b. For the purpose of rating a flare an average candlepower is needed. There was much consideration in deciding the best method of computing average candlepower. Several methods were proposed and discussed. Since the cells located on the down wind side are smoke attenuated, it would not be fair to use these cells in computing an average candlepower as this would underestimate the true value of the flare output. It seemed that the best way would be to take the average of only those cells in the up wind half. However, this presented a problem. Due to shifting winds and swirling smoke it is not always easy to determine which cells are in the up wind half and are not smoke attenuated at the instant the photograph was taken. It was felt that at any time approximately one-half of the cells would be smoke attenuated which would cause one-half of the candlepower readings to be low. Therefore, it was decided that the easiest and most accurate way to compute average candlepower for a flare was to average the candlepower of those cells whose candlepower was in the top half of the candlepower readings. Cells 56 and 57 which are horizontal to the flare are not used in this computation. The candlepower data cards are sorted to arrange them in order of magnitude and are then fed into a computer programmed to find the mean and standard deviation of the highest half (high 28) of the candlepower readings for each sample in time. The average candlepower of a flare is then found by taking the average of these means.

c. Flares were also rated by the average candlepower given by the continuous recordings R_1 or R_2. Only the one which was up wind was used. In all cases the continuous recorder that was used had its cell looking in the direction that was within 45° of the wind vector. The average candlepower was found by hand integrating the continuous recordings with a planimeter over a period of 60 seconds or 120 seconds depending upon the burning time of the flare. R_1 was used for tests 2 through 12 and R_2 was used for tests 13 through 26.

TEST RESULTS AND ANALYSIS

1. Test Results.

a. Table 1 shows the candlepower for each sample in time and the average over-all times, based on the average of the high 28 cells, for 18 flare systems tested at the MAPI test site. Sample number 8 was not used to compute the over-all mean in some cases since this candlepower was much lower than normal because the flare was about burned out when this sample was taken. Also, as can be seen from Table 1, there were less than 8 samples taken for some of the flares.

b. The over-all flare averages from Table 1 along with the candlepower obtained by integration of R_1 or R_2 recordings are shown in Table 2. Adjacent R_1 and R_2 and high 28 readings are for the same flare. Figures 5 and 6 are graphs of these candlepower readings of R_1 and R_2 and high 28 cells, respectively. There was no data to compute high 28 values for tests 21 through 26 because of instrumentation malfunction. However, data was obtained on the continuous recordings for these tests.

c. Other data shown in Table 2 includes results of field tests conducted at Patuxent River, Maryland and candlepower of Mk 24's which were burned in the light tunnel at NAD Crane. The Mk 24 tunnel readings are for flares taken from the same batches as the Mk 24's tested at the MAPI test site.

2. Correlation of R_1 and R_2 Versus High 28 Cells. The candlepower readings computed by using R_1 and R_2 averaged approximately 7.5% higher than the readings found by using the high 28 cells. The correlation between the two methods is shown in Figure 7. If the two methods gave the same readings, all points

would lie on the dotted line (one to one line). However, the line of best fit for the points is approximately 7.5% above the one to one line.

3. Correlation of Tunnel Versus MAPI Test Site. For the Mk 24's there was good correlation for batch averages between tunnel data and MAPI data. No other correlation could be made since the other flares were not burned in the light tunnel. Each time flares were tested at the MAPI test site, Mk 24's from the same batch were tested at both the MAPI test site and in the light tunnel. The batch averages are shown graphically in Figures 8 and 9. In both cases, tunnel versus R_1 and R_2 and tunnel versus high 28 cells, the points lie close to the one-to-one line, thereby increasing the confidence in MAPI test site data.

4. Analysis of Data.

a. The data for the high candlepower flares was analyzed to try to determine if any flare system or group of flare systems rated higher than others. An analysis of variance and multiple range test were run on the data for each method of rating a flare. The mean and standard deviation for each type of flare system are shown in Table 3 and the means are shown graphically ranked in order in Figure 10. The analysis of variance of the high 28 cells data showed a significant difference between types with the three Mk 24's - horizontal being significantly higher than the rest and the 7½-inch candle-horizontal being significantly lower than the others. No significant difference could be shown between the other four types. Although the analysis of variance on the R_1 and R_2 data also showed a significant difference between types, there were no definite divisions between types. As can be seen in Figure 6, there is a general decrease in candlepower going from each type to the next. Because of the small sample size and the large within type variation, it was not possible to show significant difference between any two adjacent types. There was more within type variation of the R_1 and R_2 data than for the high 28 cells data.

b. Even though no significant difference could be shown, it should be noted that for all cases of the multiple flare systems the horizontal configurations yielded a higher average candlepower as seen from the ground than the vertical configurations. Therefore, there is an indication that the horizontal arrangement might be more efficient.

c. For one flare of each type the horizontal candlepower computed from cell 57 is shown in Table 3. Cell 57 was located on one of the towers horizontal to the burning flare and on the upwind side. The horizontal candlepower of the multiple horizontal flare systems was considerably less than the average candlepower seen from the ground due to the fact that the cell could not see all of the flares of the system. However, the horizontal candlepower of the other systems was higher than the average candlepower seen from the ground.

d. The field test data from Patuxent River listed in Table 3 shows a much different ranking order for types of flares than was found at NAD Crane. In view of all the data the decision of which flare system should be considered further should be based more upon ease of manufacture, cost, reliability, etc., than upon the candlepower readings of present data.

5. Burning Rate. Additional information including candle sizes, burning time, efficiencies, etc., of the different systems of flares tested are

found in Table 4. The burning rates in inches per second which are listed in Table 5 are approximately the same for all systems.

6. Efficiency. The efficiencies in candlepower-seconds per gram are shown in Table 6. For the single Mk 24's the efficiency from the tunnel data is about the same as the efficiency from the MAPI data of the high 28 cells. The efficiency of the multiple systems of nitelites rates about the same as the efficiency of a single Mk 24 while the 7½-inch candles and the multiple systems of Mk 24's rate lower in efficiency.

7. Candlepower versus Cross Sectional Area and Diameter. In Figure 11 candlepower is plotted against diameter and cross sectional area of the flare. For the individual units which were burned vertically, there seems to be a straight line relationship between candlepower and cross sectional area as shown by the straight line on the graph. This is also shown by the curved line effect of the same candles on the graph of candlepower versus diameter.

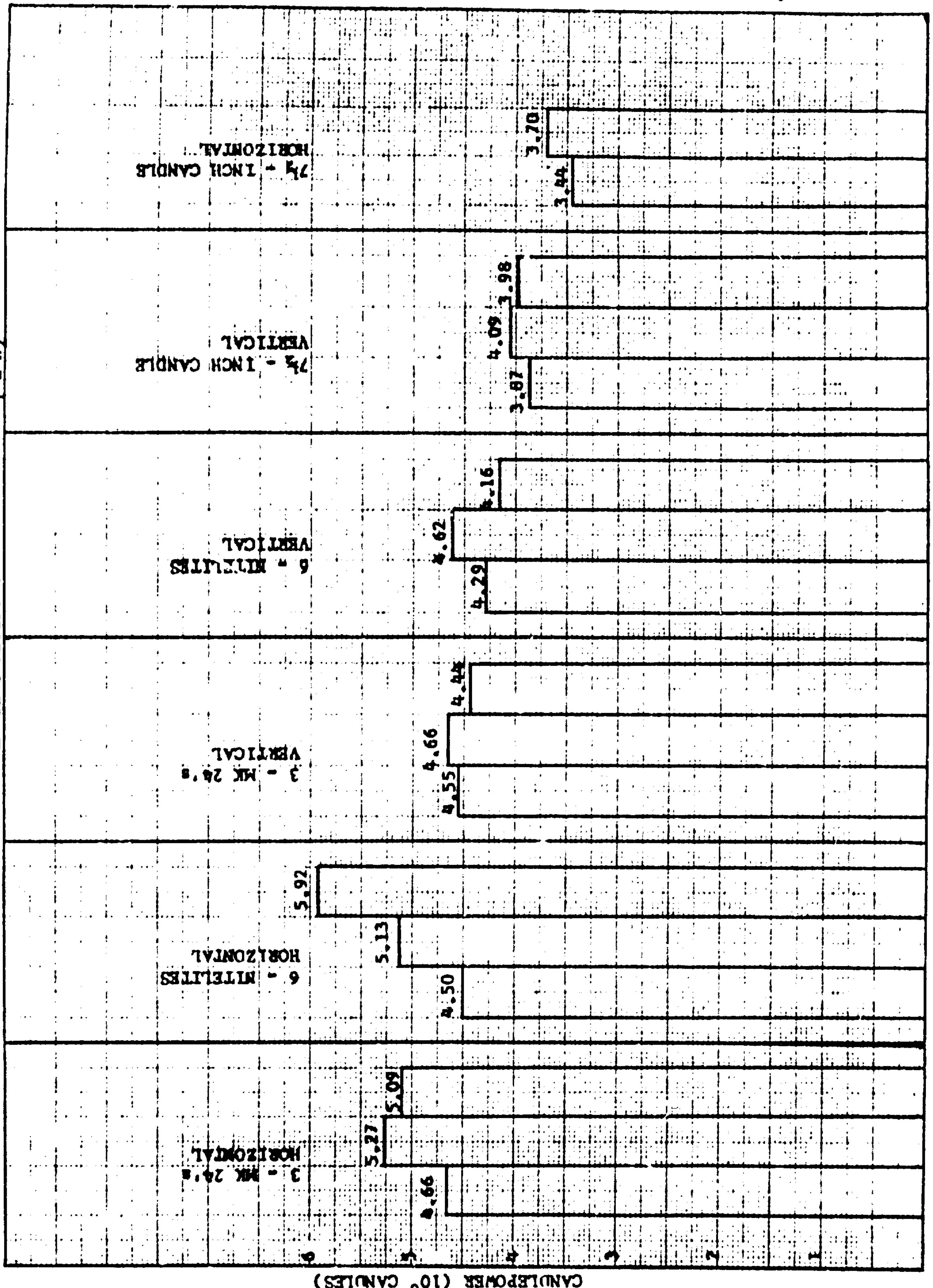

AVERAGE CANDLEPOWER
R_1 & R_2
7½ - INCH CANDLE
HORIZONTAL
3.70
3.84
7½ - INCH CANDLE
VERTICAL
3.98
4.09
3.87
6 - MITELITES
VERTICAL
4.16
4.62
4.29
3 - MK 24's
VERTICAL
4.66
4.55
6 - MITELITES
HORIZONTAL
5.92
5.13
4.50
3 - MK 24's
HORIZONTAL
5.09
5.27
4.66
6
5
4
3
2
1
CANDLEPOWER (10^6 CANDLES)

FIGURE 5

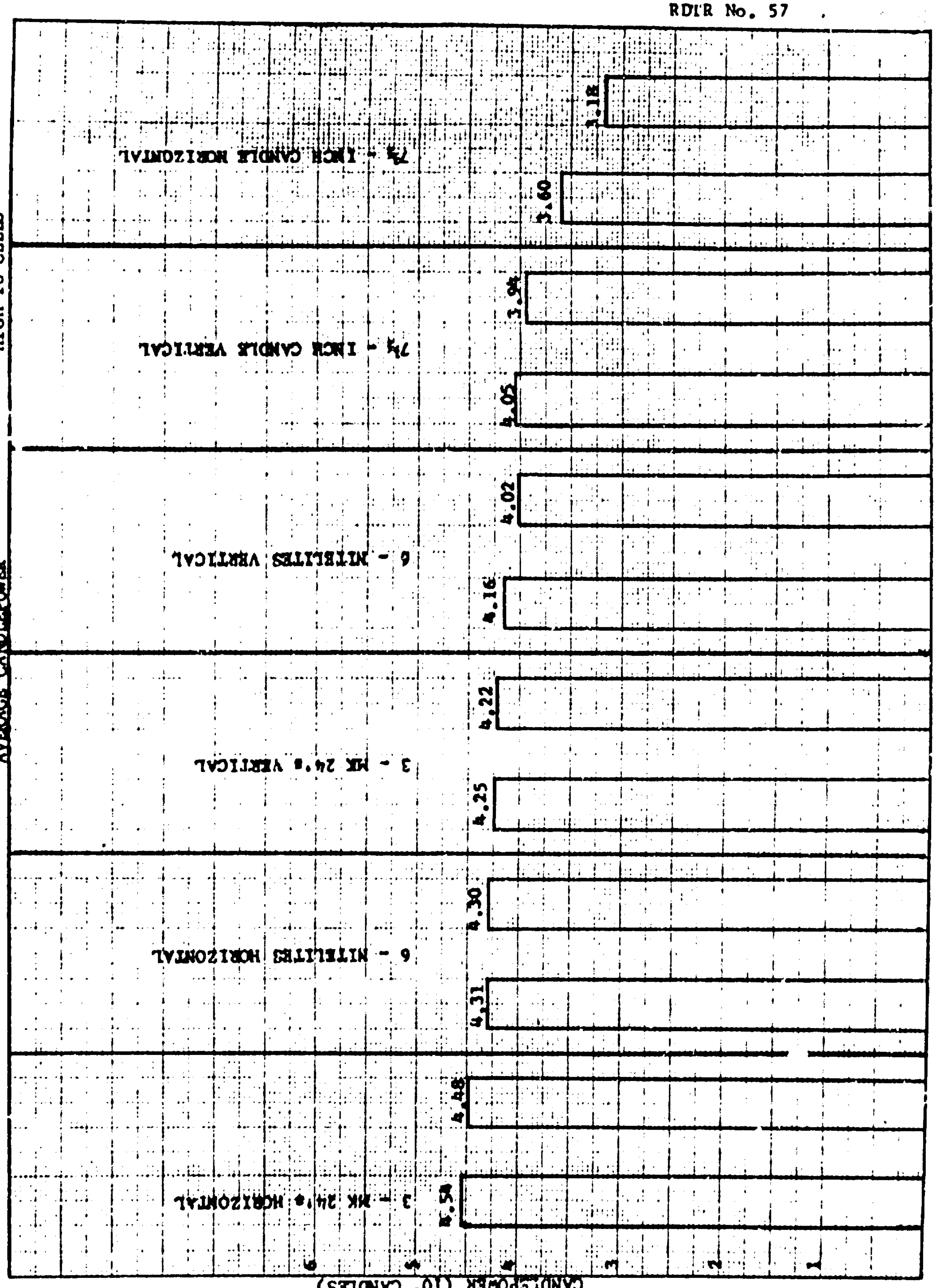

HIGH 28 CELLS
AVERAGE CANDLEPOWER
7¾ - INCH CANDLE HORIZONTAL
3.18
3.60
7¾ - INCH CANDLE VERTICAL
3.94
4.05
6 - NITELITES VERTICAL
4.02
4.16
3 - MK 24's VERTICAL
4.22
4.25
6 - NITELITES HORIZONTAL
4.30
4.31
3 - MK 24's HORIZONTAL
4.48
CANDLEPOWER (10^6 CANDLES)

FIGURE 6

CORRELATION OF R_1 & R_2 VERSUS HIGH 28 CELLS

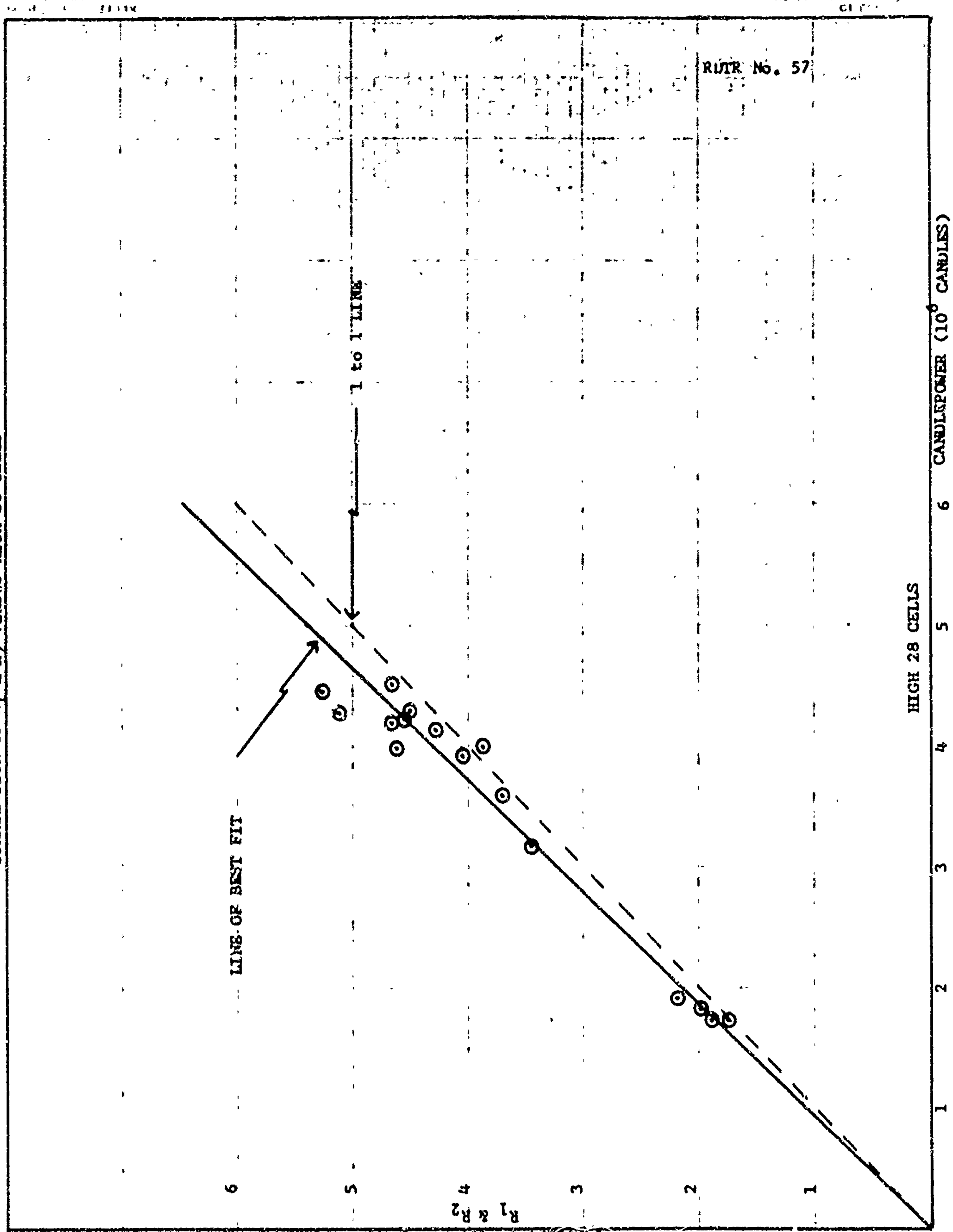
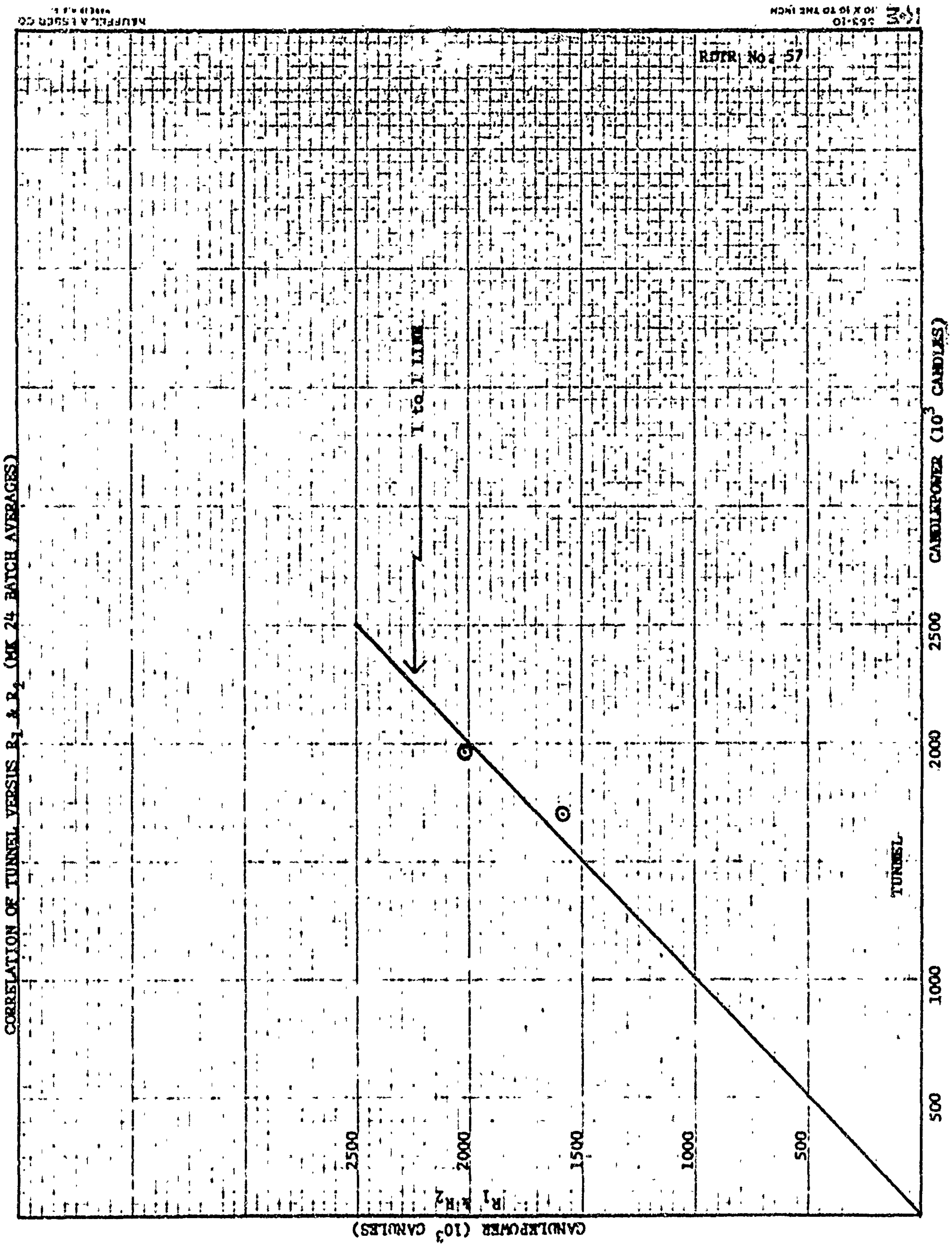


FIGURE 7



CORRELATION OF TUNNEL VERSUS R_1 & R_2 (MK 24 BATCH AVERAGES)
RDTR No. 57
1 to 1 LINE
TUNNEL
CANDLEPOWER (10^3 CANDLES)
R_1 & R_2
CANDLEPOWER (10^3 CANDLES)
500
1000
1500
2000
2500

FIGURE 9

CORRELATION OF TUNNEL VERSUS HIGH 28 CELLS (MK 24 BATCH AVERAGES)

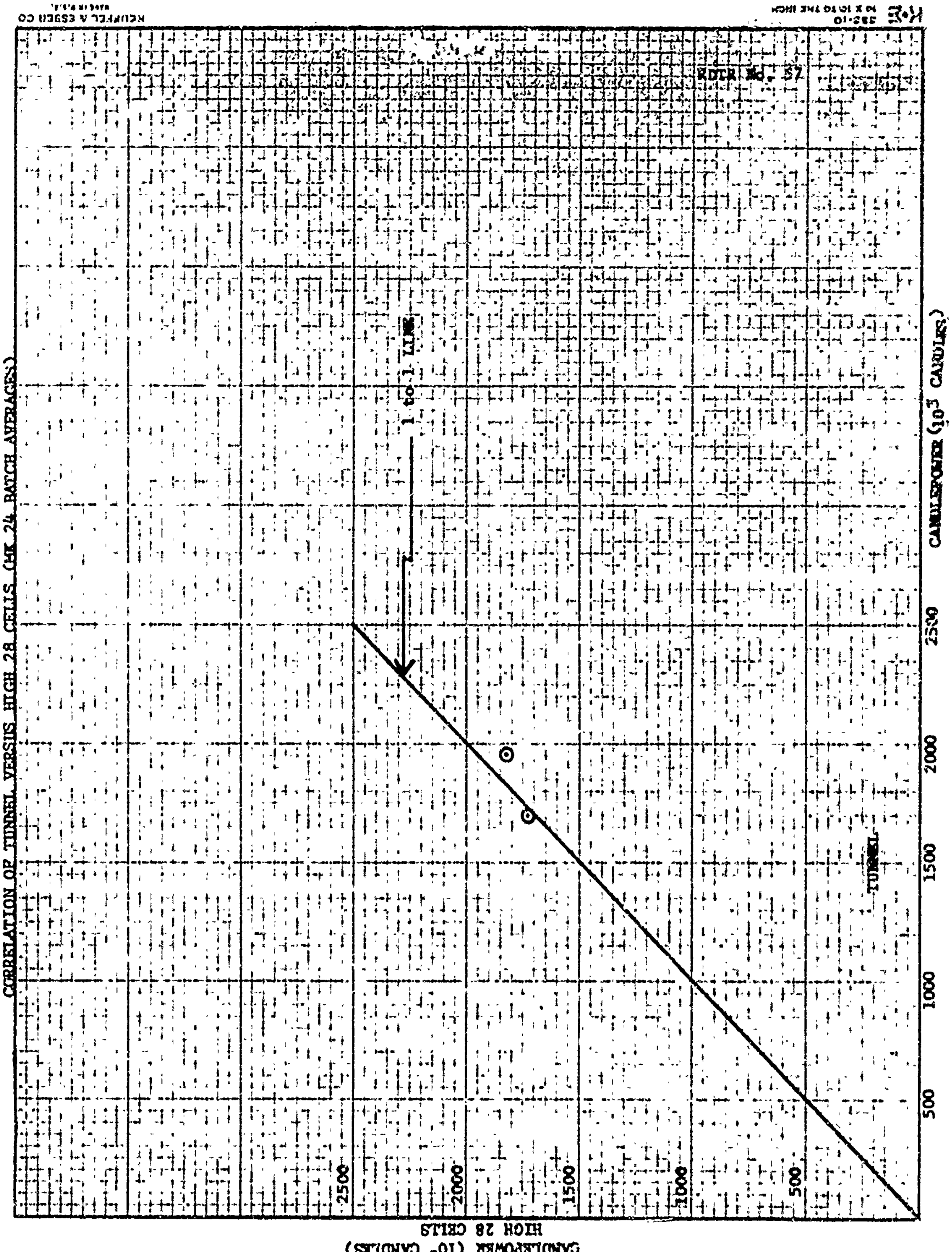


FIGURE 9

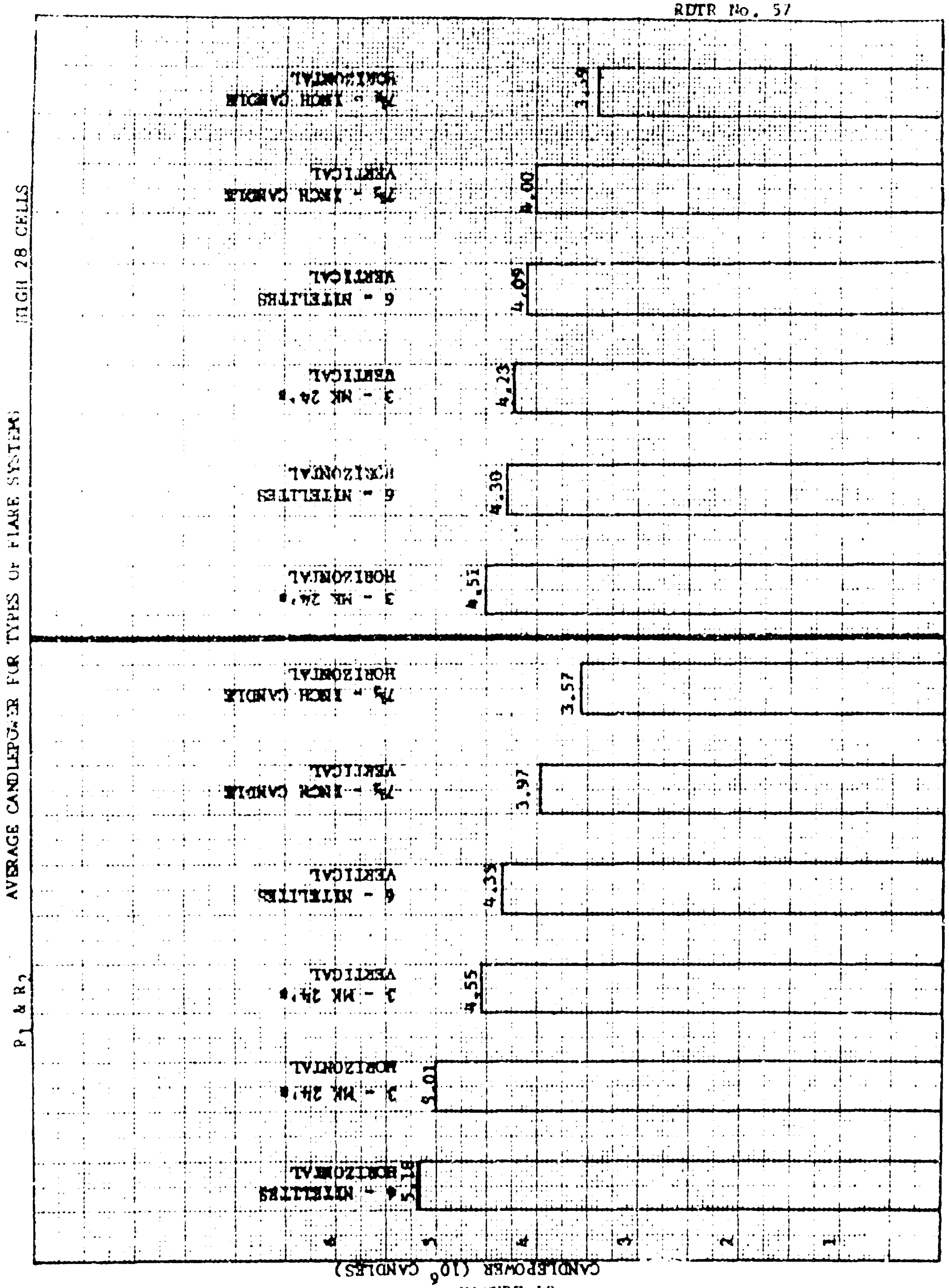

AVERAGE CANDLEPOWER FOR TYPES OF FLARE SYSTEMS
P1 & R2
HIGH 28 CELLS
4 - NITELITES HORIZONTAL
5.18
3 - MK 24's HORIZONTAL
5.01
3 - MK 24's VERTICAL
4.55
6 - NITELITES VERTICAL
4.33
7½ - INCH CANDLE VERTICAL
3.97
7½ - INCH CANDLE HORIZONTAL
3.57
3 - MK 24's HORIZONTAL
4.51
6 - NITELITES HORIZONTAL
4.30
3 - MK 24's VERTICAL
4.23
6 - NITELITES VERTICAL
4.09
7½ - INCH CANDLE VERTICAL
4.00
7½ - INCH CANDLE HORIZONTAL
3.39
6
5
4
3
2
1
CANDLEPOWER (10^6 CANDLES)

FIGURE 10

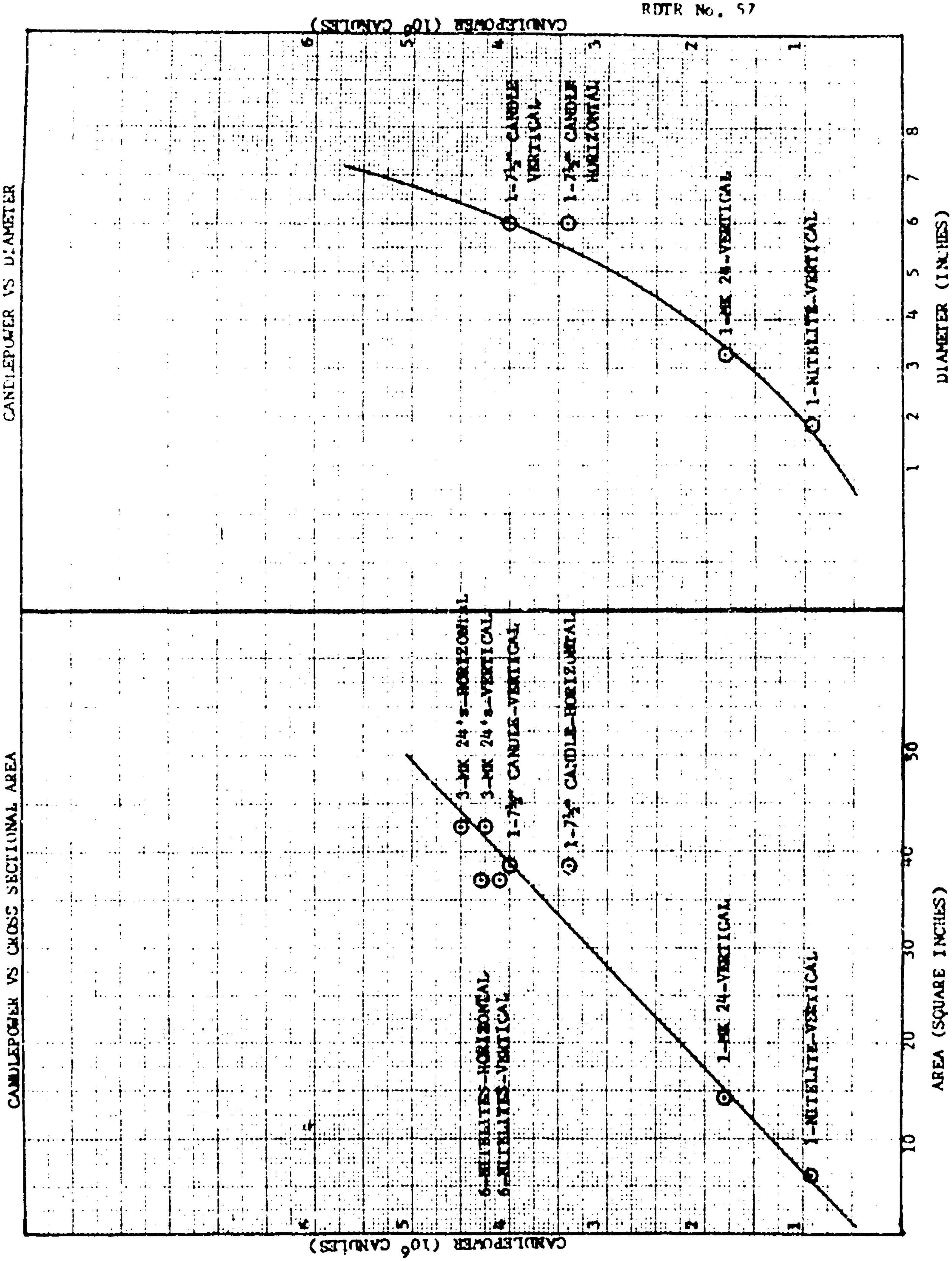

CANDLEPOWER VS CROSS SECTIONAL AREA
CANDLEPOWER VS DIAMETER
CANDLEPOWER (10^6 CANDLES)
AREA (SQUARE INCHES)
DIAMETER (INCHES)
1-NITELITE-VERTICAL
1-MK 24-VERTICAL
6-NITELITES-HORIZONTAL
6-NITELITES-VERTICAL
3-MK 24's-HORIZONTAL
3-MK 24's-VERTICAL
1-7½" CANDLE-VERTICAL
1-7½" CANDLE-HORIZONTAL
1-7½" CANDLE VERTICAL
1-7½" CANDLE HORIZONTAL
1-MK 24-VERTICAL
1-NITELITE-VERTICAL

FIGURE 11

TABLE 1
AVERAGE CANDLEPOWER FROM HIGH 28 CELLS FOR EACH SAMPLE IN TIME
(THOUSAND CANDLES)

Test No.	Type of Flare System	Time 1	2	3	4	5	6	7	8	n	$\bar{x}$
2	1-Mk 24 Mod 2	1,700	1,944	1,859	1,837	1,928	1,925	1,807	465*	7	1,857
3	1-Mk 24 Mod 3	1,820	1,932	2,203	1,662	1,821	2,205	1,739		7	1,912
4	6-Nitelites Vertical	3,919	3,786	3,999	4,301	4,333	4,478	4,271	3,473*	7	4,155
5	7½ Inch Candle Vertical	3,961	3,891	3,913	4,296	3,944	4,165	4,175	484*	7	4,049
6	3-Mk 24's Vertical	4,080	4,034	5,155	4,361	3,869	4,272	3,983	2,848*	7	4,251
7	6-Nitelites Horizontal	2,882	4,636	3,330	5,197	4,696	4,839	4,299	4,615	8	4,312
8	7½ Inch Candle Horizontal	3,127	2,900	3,628	3,912	3,538*	3,586	3,935	4,143	7	3,604
9	3-Mk 24's Horizontal	4,702	4,485	4,366	4,418	4,322	4,810	4,648	1,032*	7	4,536
10	1-Nitelite	1,010	974	963	903	847	915	891	854	8	920
11	1-Mk 24 Mod 3	1,711	1,991	1,975	1,756	1,797	1,919	1,691		7	1,834
12	1-Mk 24 Mod 3	1,648	1,679	1,835	1,744	1,697	1,839	1,750	1,694	8	1,736
13	1-Mk 24 Mod 3	1,218*	1,858	1,845	1,702	1,681	1,663	1,671		6	1,737
14	6-Nitelites Horizontal		No data - instrumentation failure								
15	6-Nitelites Vertical	3,840	4,256	3,717	4,391	4,372	4,035	3,552	331*	7	4,023
16	7½ Inch Candle Horizontal	3,606	3,357	3,362	2,825	2,906	3,042			6	3,183
17	3-Mk 24's Horizontal	4,599	5,051	4,299	4,368	4,434	5,035	3,542		7	4,475
18	7½ Inch Candle Vertical	3,725	3,697	3,537	3,933	2,968*	4,008	4,375	4,314	7	3,941
19	3-Mk 24's Vertical	4,115	4,887	4,542	4,295	3,802	3,532	4,353	1,181*	7	4,218
20	6-Nitelites Horizontal	4,368	4,127	3,802	5,156	5,030	4,246	3,616	4,029	8	4,297

* Not used in computing $\bar{x}$ because of incomplete data or flare was burning out.

TABLE 2
AVERAGE CANDLEPOWER FOR INDIVIDUAL FLARE SYSTEMS

	MAPI TEST SITE R_1 & R2	MAPI TEST SITE High 28	PATUXENT RIVER	CRANE TUNNEL
3-Mk 24's Horizontal	4,665,000 5,274,000 5,094,000	4,536,000 4,475,000	3,570,000 4,760,000	
6-Nitelites Horizontal	4,496,000 5,127,000 5,925,000	4,312,000 4,297,000	5,010,000 3,820,000	
3-Mk 24's Vertical	4,546,000 4,658,000 4,444,000	4,251,000 4,218,000	4,260,000 5,100,000 4,320,000	
6-Nitelites Vertical	4,287,000 4,616,000 4,156,000	4,155,000 4,023,000	3,780,000 4,130,000 4,460,000	
7½-Inch Candle Vertical	3,870,000 4,049,000 3,982,000	4,049,000 3,941,000	3,190,000	
7½-Inch Candle Horizontal	3,701,000 3,441,000	3,604,000 3,183,000	4,130,000	
1-Mk 24 Mod 3 Vertical	2,168,000 1,980,000 1,890,000 1,745,000 1,432,000	1,912,000 1,834,000 1,736,000 1,737,000	1,600,000	2,079,000 1,900,000 1,900,000 1,722,000 1,675,000 1,718,000 1,702,000

TABLE 3
AVERAGE CANDLEPOWER FOR TYPES OF FLARE SYSTEMS

	R_1 & R_2	High 28	Horizontal CP Cell 57	Crane Tunnel	Patuxent River
3-Mk 24's Horizontal	n=3 $\bar{x}$=5,011,000 s=313,000	n=2 $\bar{x}$=4,506,000 s=43,000	n=1 $\bar{x}$=3,274,000		n=2 $\bar{x}$=4,165,000 s=842,000
6-Nitelites Horizontal	n=3 $\bar{x}$=5,183,000 s=716,000	n=2 $\bar{x}$=4,304,000 s=11,000	n=1 $\bar{x}$=2,855,000		n=2 $\bar{x}$=4,415,000 s=842,000
3-Mk 24's Vertical	n=3 $\bar{x}$=4,549,000 s=107,000	n=2 $\bar{x}$=4,234,000 s=23,000	n=1 $\bar{x}$=5,492,000		n=3 $\bar{x}$=4,560,000 s=469,000
6-Nitelites Vertical	n=3 $\bar{x}$=4,353,000 s=237,000	n=2 $\bar{x}$=4,089,000 s=93,000	n=1 $\bar{x}$=4,944,000		n=3 $\bar{x}$=4,123,000 s=340,000
7½-Inch Candle Vertical	n=3 $\bar{x}$=3,967,000 s=90,000	n=2 $\bar{x}$=3,995,000 s=76,000	n=1 $\bar{x}$=5,291,000		n=1 $\bar{x}$=3,190,000
7½-Inch Candle Horizontal	n=2 $\bar{x}$=3,571,000 s=184,000	n=2 $\bar{x}$=3,394,000 s=298,000	n=1 $\bar{x}$=3,898,000		n=1 $\bar{x}$=4,130,000
1-Mk 24 Vertical	n=5 $\bar{x}$=1,847,000 s=282,000	n=4 $\bar{x}$=1,805,000 s=85,000	n=1 $\bar{x}$=2,235,000	n=7 $\bar{x}$=1,814,000 s=150,000	n=1 $\bar{x}$=1,600,000

TABLE 4
MISCELLANEOUS DATA

Test	Type of Flare System	Hi 28 CP 10^3	BT Sec	CP-Sec 10^6	Weight of Comp Lb	Weight of Comp Grams	EFF CP-Sec g	BR g/sec	Length In.	BR In/Sec	Cross Section Area In^2
2	1-Mk 24 Mod 2	1857	155	288	12.8	5806	49,580	37.5	13.78	.089	14.2
3	1-Mk 24 Mod 3	1912	151	289	15	6804	42,430	45.1	16.75	.111	14.2
4	6-Nitelites V.	4155	70	291	---	6600	44,070	94.8	7.19	.103	36.9
5	7½-Inch Candle V.	4049	61	247	17	7711	32,030	127.2	7.00	.116	38.5
6	3-Mk 24's V.	4251	172	731	45	20412	35,820	118.7	16.75	.097	42.6
7	6-Nitelites H.	4312	67	289	---	6600	43,770	98.5	7.19	.107	36.9
8	7½-Inch Candle H.	3604	64	231	17	7711	29,910	120.5	5.75	.090	38.5
9	3-Mk 24's H.	4536	160	726	45	20412	35,560	127.6	16.75	.105	42.6
10	1-Nitelite	920	73	67	---	1100	61,050	15.1	7.19	.098	6.2
11	1-Mk 24 Mod 3	1834	172	315	15	6804	46,360	39.6	16.75	.097	14.2
12	1-Mk 24 Mod 3	1736	165	286	15	6804	42,098	41.2	16.75	.102	14.2
13	1-Mk 24 Mod 3	1737	174	302	15	6804	44,420	39.1	16.75	.096	14.2
14	6-Nitelites H.	---	65	---	---	6600	------	101.5	7.19	.111	36.9
15	6-Nitelites V.	4023	64	257	---	6600	39,010	103.1	7.19	.112	36.9
16	7½-Inch Candle H.	3183	75	239	---	7711	31,000	102.8	5.75	.077	38.5
17	3-Mk 24's H.	4475	158	707	45	20412	34,638	129.2	16.75	.106	42.6
18	7½-Inch Candle V.	3941	72	284	---	7711	37,000	107.1	7.00	.097	38.5
19	3-Mk 24's V.	4218	160	675	---	20412	33,060	127.6	16.75	.105	42.6
20	6-Nitelites H.	4297	69	296	---	6600	44,920	95.7	7.19	.104	36.9
21	6-Nitelites V.	----	67	---	---	6600	------	98.5	7.19	.107	36.9
22	3-Mk 24's H.	----	155	---	45	20412	------	131.7	16.75	.108	42.6
23	7½-Inch Candle H.	----	71	---	17	7711	------	108.6	7.00	.081	38.5
24	3-Mk 24's V.	----	154	---	45	20412	------	132.5	16.75	.109	42.6
25	7½-Inch Candle V.	----	65	---	17	7711	------	118.6	7.00	.088	38.5
26	1-Mk 24 Mod 3	----	180	---	15	6804	------	37.8	16.75	.093	14.2

TABLE 5

BURNING RATE (IN/SEC)

6-Nitelites Horizontal	.107 .111 .104
6-Nitelites Vertical	.103 .112 .107
3-Mk 24's Horizontal	.105 .106 .108
3-Mk 24's Vertical	.097 .105 .109
7½-Inch Candle Vertical	.116 .097 .088
7½-Inch Candle Horiztonal	.090 .077 .081
1-Mk 24 Mod 3	.111 .097 .102 .096 .093

TABLE 6
EFFICIENCY (CP-SEC/GRAM)

	High 28	R_1 & R_2	Tunnel
6-Nitelites Horizontal	44,000 45,000	46,000 54,000 58,000	
6-Nitelites Vertical	44,000 39,000	45,000 45,000 42,000	
3-Mk 24's Horizontal	36,000 35,000	37,000 41,000 39,000	
3-Mk 24's Vertical	36,000 33,000	38,000 36,000 34,000	
7½-Inch Candle Vertical	32,000 37,000	31,000 38,000 34,000	
7½-Inch Candle Horizontal	30,000 31,000	31,000 34,000	
1-Mk 24 Mod 3	42,000 42,000 44,000 46,000	49,000 46,000 45,000 50,000 38,000	44,000 42,000 44,000 44,000